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## **TITLE PAGE**

### **MANUSCRIPT TITLE**

THE EFFECTS OF WHOLE BODY VIBRATION IN ISOLATION OR COMBINED WITH STRENGTH TRAINING IN FEMALE  
ATHLETES

### **RUNNING HEAD**

WBV in isolation or combined with strength training

### **LABORATORY**

The research was conducted in the “Laboratorio di Fisiologia Sperimentale Applicata  
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THE EFFECTS OF WHOLE BODY VIBRATION IN ISOLATION OR COMBINED WITH STRENGTH TRAINING IN FEMALE  
ATHLETES

**ABSTRACT**

The aims of this study were to assess the behaviour of a vibrating platform under different conditions and to compare the effects of an 8-weeks periodised training programme with whole body vibration (WBV) alone or in combination with conventional strength training.

Vibrating frequencies, displacements and peak accelerations were tested through a piezoelectric accelerometer under different conditions of load and subjects' position. Eighteen national level female athletes were assigned to one of three different groups performing WBV, conventional strength training (ST), or a combination of the two (WBV+ST). Isometric maximal voluntary contraction, dynamic maximal concentric force, and vertical jump tests were performed before and after the conditioning programme.

Vibrating displacements and maximum accelerations measured on the device were not always consistent with their expected values calculated from the display and manufacturers' information (sinusoidal waveforms). WBV alone or in combination with low intensity resistance exercise did not seem to induce significant enhancements in force and power when compared to ST.

It appears that WBV cannot substitute parts of strength training loading in a cohort of young female athletes. However, vibration effects might be limited by the behaviour of the commercial platforms as the one used in the study. More studies are needed to analyse the performances of devices and the effectiveness of protocols.

**KEY WORDS**

Vibration exercise, resistance training, muscle performance, women

## INTRODUCTION

Whole body vibration (WBV) has been suggested as an alternative training modality capable of enhancing strength and power in various populations (8,10,12). This alternative mode of exercise consists performing static or dynamic squatting on oscillating platforms producing vertical sinusoidal vibrations (1). Many authors have ascribed the observed increase in electromyographic (EMG) activity during WBV (1,9,16) to physiological mechanisms similar to the ones observed with the tonic vibration reflex (TVR). The observed increase in EMG activity during WBV exercise has been also suggested to be related to muscle tuning activity necessary to damp the vibratory waves (11,39,40,41), suggesting that such modality could influence motor unit activation patterns when an appropriate vibration magnitude is applied. It has been hypothesised that the WBV effectiveness as an exercise modality aimed at improving strength and power in various populations is due to the increased neuromuscular activity observed. Despite the lack of consensus on the acute effects of WBV (11,12,21,31,35), many studies have been conducted to evaluate its efficacy when implemented as a medium to long term training modality.

For example, two studies (32,42) demonstrated that 6 weeks of WBV training produced significant changes in sprint running kinematics and explosive strength performance and maintained jump performance in healthy individuals. Different authors have shown that WBV training may improve maximal strength and explosive power in recreationally resistance-trained men, with vibration applied during resistance exercise (38) or added prior to or between sets of resistance exercise (25). Furthermore, Delecluse et al. (16) found that 12 weeks of WBV training performed with frequencies of 35-40 Hz and magnitudes of 2.28 and 5.09 g

(where  $1\text{ g} = 9.81\text{ m}\cdot\text{s}^{-2}$ ) was as effective as a low intensity resistance training modality in healthy untrained young women.

While the above mentioned studies are very promising and support the idea of the efficacy of WBV and similar forms of vibration training in improving force and power generating capacity in humans, it is still debatable if such modality could be effective in well trained athletes. In fact, Delecluse et al. (17) showed that a WBV training protocol of 5 weeks did not improve strength or power in the lower limbs of well trained sprinters. Recent work from Kvorning et al. (22) reported that combining WBV with conventional resistance exercise (six sets x eight reps with a load equal to 8 repetition maximum) for a 9-weeks training period did not improve maximal voluntary contraction and vertical jumping ability more than resistance training alone in young men. Similarly, Lamont et al. (23) showed no gains in performing squats on vibrating platforms with a 6-weeks periodised programme in males. However, various authors suggested this modality to be effective in improving strength and power of the lower limbs in particular in young athletes (26), in female athletes (18) and ballerinas (3). To our knowledge, few studies have been so far conducted to analyse the effectiveness of WBV exercise alone or in combination with conventional resistance exercise programmes in well trained female athletes. Recently, Fernandez-Rio et al. (20) showed that the application of WBV had no advantages over traditional strength training methods in female basketball players. The same results were recently shown by Carson et al. (14) using calf raise exercises.

Most of the conflicting results are due to the difference in training protocols and training modes used, but most of all in the equipment utilised. Various studies conducted in our labs on

various vibrating platforms have highlighted the limitations of many devices and the alterations in vibration parameters (amplitude and frequency) when individuals with different body mass and/or lifting weights on such platforms perform squatting exercises (13). Furthermore a recent work from Pel et al. (33) using 3 commercially available units supports our findings.

Clearly, there is a lack of information in the current literature on the combined effects of WBV and strength training on force and power generating capacity of the lower limbs in female athletes which makes difficult for strength and conditioning coaches to prescribe effective use of such technology. Furthermore, there are limited reports analysing the performance of vibrating platforms when people are exercising with extra loads on them, making difficult for the practitioners to identify limitations for heavy individuals or individuals planning to lift heavy weights on a platform. For this reason, we conducted this study with the primary aim of understanding the behaviour of a vibrating platform when squatting with extra load. The secondary aim of this study was to analyse the effects of WBV alone or in combination with resistance exercise on force and power generating capacity of the lower limbs in such population. We hypothesised that the acceleration of the vibrating platform was affected by the total mass (body mass + external load) of the exercising individual and the WBV + strength training protocol was superior to WBV alone and strength training in eliciting an improvement in strength and power of the lower limbs in a group of well trained females.



## METHODS

### *EXPERIMENTAL APPROACH TO THE PROBLEM*

The consistency of the vibrating characteristics when athletes train on the platform was tested by measuring vibrating frequency, amplitude and peak acceleration (dependent variables) under different condition of pre-set vibrating frequency and load on the platform (independent variables). Changes of weight were meant to verify if and how the load acting on the platform affects the vibrating performance. Modifications of body position were also used to simulate the possible different phases of squatting exercises and the body stiffness derived thereof.

The effectiveness of WBV, applied alone or in combination with strength training was assessed through a set of tests aimed at comparing force/power-generating abilities before and after the conditioning intervention (within-subjects factor). The control group consisted in athletes following a conventional strength training protocol. A multiplicity of parameters (with each of those being the dependent variable) was estimated from isometric maximal voluntary contraction tests, dynamic maximal concentric force, and vertical jump tests. The independent variables were: time and group, for the isometric and jumping test; time, group and load, for the dynamic force test.

### *SUBJECTS*

Eighteen national level female athletes (all data are reported as mean $\pm$ standard deviation: age, 23.8 $\pm$ 4.6 years; height, 166.3 $\pm$ 5.4 cm; weight, 58.8 $\pm$ 7.8 kg; fat mass, 19 $\pm$ 7.6 %) volunteered to participate in the study. Informed consent was obtained from each subject and the study was approved by the local institutional review board (IRB). All athletes belonged to team sports (12

were on the soccer team, 6 were on the softball team), competing in the Italian first division and performing 4 training sessions weekly plus the match. No subjects were experienced with WBV training. The subjects were randomly assigned to 3 different training groups of 6 people each (Table 1): a WBV group (WBV); a conventional strength-training group (ST); a combined strength-training (conventional and WBV) group (WBV+ST).

\*\*\*\* Table 1 near here \*\*\*\*

## PROCEDURES

### *Vibrating platform validation*

The characteristics of the vibrating platform (Nemes LX-B/E, SAIR, Italy) were tested before the experimental procedure. Vibration frequency ( $f$ ), amplitude ( $A$ ) and peak acceleration ( $a_{peak}$ ) were measured as suggested by Rauch et al. (36) by a piezoelectric accelerometer (353B17 PCB Piezotronics, Depew, USA) under 3 different loading conditions on the platform: no load (L0), with a subject of 55 kg (L1) and with a subject of 90 kg (L2). Furthermore, for L1 and L2, the platform's behaviour was tested in 3 different lower limbs' positions: knees flexed at 90 deg, knees flexed at 45 deg and extended knees with heel raised. In L2, a subject of 90 kg was used instead of adding an external load to the L1 subject. This was done to avoid possible hazardous conditions in which the 55 kg subject should have held a heavy weight on the vibrating platform in uncomfortable positions. The accelerometer was fixed using two bolts at the centre of the platform, and its sampling rate was set at 1000 Hz. Acceleration data were collected over a time span of 5 s for each frequency that the platform allowed (i.e. from 20 to 55 Hz, with steps of 5

Hz).  $a_{peak}$  and  $A$  were obtained directly from acceleration data or by double integrating them.  $f$  was defined as the peak of the power spectrum of the acceleration waveform.

### *Training study*

#### Training programme

In consultation with the coaches of the different sports teams the experimental protocol was implemented in the conventional training program during the winter preparatory period (January and February). During these two months, any training sessions dealing with maximal strength and power were stopped.

All the subjects carried out a periodised 8-weeks training programme, which consisted of 2 cycles of 3 weeks, followed by one week of tapering (Table 2).

\*\*\*\* Table 2 near here \*\*\*\*

The 2 training sessions per week were separated by 72 hours of recovery. Hence, each athlete completed as many as 16 strength training sessions, which integrated their usual workouts on the field. The latter included: speed training drills, aerobic qualities, development of technical and tactical skills. Possible bias induced by the effects of different field training procedures could be considered negligible because: (i) all the subjects belonged to the same teams and performed the same number and type of workouts; (ii) attention was paid in distributing homogeneously soccer and softball player over the 3 groups (Table 1); (iii) the characteristics of

each training session were written down into a personal daily diary and later controlled. The diary was also used to collect the athletes' perception of discomfort, after each training session or over the following days, and to annotate menstrual periods. None of the subjects took oral contraceptives before and during the experimental protocol.

Two familiarization sessions preceded the experimental training programme in order to control proper squat technique and to experience with the WBV. All training sessions were individually supervised in order to control training techniques and training loads. A standardized 10-minute warm-up that incorporated light jogging and whole-body stretching was administered before all session. Each participant completed during each training session 6 sets of 6 reps, performing squats at a knee angle of 90 deg with feet slightly rotated externally, with 3 minutes rest between each set. Dynamic squats were performed for all groups with explosive contractions during the concentric phase, slowly bending the knees during the controlled eccentric phase. Cadence (5 s) and depth (90 deg) were set and rigorously monitored.

Group WBV carried out the exercise on a vibrating platform (Nemes LX-B/E, SAIR, Italy) (Figure 1a); group ST used standard weight loaded barbells (Figure 1b); group WBV+ST performed squatting with the barbell while standing on the vibrating platform (Figure 1c). Vibration frequency was initially set at 25 Hz and was increased of 5 Hz every 2 weeks for both WBV and WBV+ST. The rationale for such approach was to periodise the WBV load by increasing the magnitude of the acceleration progressively.

Bar loads were set at 60% and 30% of each subject's body mass (BM) for ST and WBV+ST, respectively, and was increased of about 6% (for ST) and 3% BM (for WBV+ST) every 2 weeks. The rationale for the difference in approach was due to two main factors: (i) the observed instability of the vibrating platform used with high loads; and (ii) the necessity to simulate a similar neuromuscular load as we envisaged the combination of weight+vibration to be similar to the weight only group with double the external mass.

\*\*\*\* Figure 1 near here \*\*\*\*

### Testing procedures

The subjects were tested before and after the end of the experimental treatments. Pre-tests were performed the week before the beginning of the intervention ( $t_i$ ), whereas the post-treatment tests were performed the week after the last training session ( $t_f$ ). Both isometric and dynamic muscular strength and power were measured. In order to avoid learning effects, subjects experienced testing procedures at least once before the first testing session. Furthermore, measures were collected at the same time of the day for  $t_i$  and  $t_f$ , limiting the influence of circadian rhythms. Proper recovery intervals were respected between sets (>3 min) and tests (>1 h between isometric and dynamic strength tests; jump tests were performed after 2 days) to prevent neuromuscular fatigue. Prior to the testing days, subjects were asked to control the ingestion of alcohol and caffeine and to refrain from smoking. They were also asked to avoid intense physical activity.

Isometric Test: isometric Maximal Voluntary Contraction (iMVC) was measured by two force platforms (Twin Plates, Globus, Italy) whose sampling frequency was 1000 Hz. They were fixed onto the foot platform of a horizontal leg press (Technogym SpA, Gambettola, Italy). The seat was locked so that the subjects' knees were flexed at 90 deg, and the back rest angle was at 45 deg (Figure 2). Three iMVC of 5 s each were performed. Data from the two platforms were summed to get the overall force curve ( $F(t)$ ). The following parameters were extracted from each trial: maximal isometric force ( $iF_{max}$ ), time to reach maximal force ( $t_{max}$ ), time to reach 30%, 50% and 90% of iMVC ( $t_{30}$ ,  $t_{50}$ ,  $t_{90}$ ). Three minutes rest were allowed in between each trial. The repetition with the highest  $iF_{max}$  was selected for statistical analysis.

\*\*\*\* Figure 2 near here \*\*\*\*

Dynamic (F-v) test: dynamic Maximal Concentric Force (dMCF) was measured by means of rapid leg extensions with a range of loads in the same setup used for isometric testing (19). The athlete was asked to start from the same position of iMVC and to exert a maximal push against the force platform, while the sledge was free to move backwards on the two horizontal rails (Figure 3). The imposed external loads corresponded to 100-120-140-160-180-200% of each individual's BM. Three repetitions for each weight were collected. Within the same external load, 10 s rest was allowed between trials. Three minutes rest were allowed between testing loads. Dynamic variables (force,  $F$ , velocity,  $v$ , and power,  $P$ ) were calculated by coupling information from the force platforms and a linear encoder (Real Power, Globus, Italy) using Newtonian laws. The sampling rate of the encoder was 1000 Hz. The analysed movement was

defined as the interval between the beginning of the push, when the force curve started raising from the baseline, and toe off, when  $F(t)$  reached the zero line. The following parameters were analysed from each trial: average power over the range of movement ( $P_{mean}$ ), maximum force, power and velocity ( $F_{max}$ ,  $v_{max}$ ,  $P_{max}$ ). For each load, the repetition with the highest  $P_{mean}$  was selected as the most representative of the subject, and the corresponding measurements were used in the statistical analysis.

\*\*\*\* Figure 3 near here \*\*\*\*

Vertical jump tests: Countermovement jumps (CMJ) and continuous countermovement jumps over 15 s (CMJ-15s) were used to assess the effects of the treatments on the explosive power of the lower limbs and jump endurance. Three maximal CMJ and one CMJ-15s were performed according to the protocol suggested by Bosco et al. (5). Ten seconds rest was allowed between each CMJ, 3 min rest was allowed before performing the CMJ-15s test. The participants were instructed to keep their hands on their hips for the duration of the jumps. They were visually monitored to control a knee angle of 90 deg during the concentric phase of each jump. Jumping height and power were calculated using flight time and contact time measured with an optical acquisition system (Optojump, Microgate Srl, Bolzano, Italy), sampling at 1000 Hz. The obtained flight time was used to determine the best height ( $H_{max}$ ) of the three CMJ, and the mean height ( $H_{mean-15s}$ ) and power ( $P_{mean-15s}$ ) of the CMJ-15s (6).

## STATISTICAL ANALYSIS

*Vibrating platform validation*

Parameters for each testing condition of load, subject position and preset frequency were reported as the median value and interquartile range over the 5 s acquisition. Differences of actual  $A$ ,  $f$  and  $a_{peak}$  from the calculated values from the device's display and manufacturer's information were described in terms of percentage differences ( $\epsilon\%$ ). The following equation describing sinusoidal oscillations:  $(a=A \cdot (2\pi \cdot f)^2)$  was used to calculate the theoretical acceleration and compare it to the measured values.

*Homogeneity of groups*

Anthropometric measurements and pre-test parameters were used to verify whether the assignment of athletes had created homogeneous groups or not. Kruskal-Wallis tests concerning the following parameters were considered: age, height, weight, body fat (physical characteristics);  $iF_{max}$ ,  $t_{max}$ ,  $t_{30}$ ,  $t_{50}$ ,  $t_{90}$  (iMVC);  $P_{mean}$  at 140% of BM (dMCF);  $H_{max}$ ,  $H_{mean}$ ,  $H_{mean-15s}$ ,  $P_{mean-15s}$  (CMJ).

*Training study*

Test-retest reliability of each dependent variable was assessed by means of intra-class correlation coefficients (ICC).

A repeated measures ANOVA (2 times (pre-post) x 3 training groups) was applied to isometric force tests and jump tests to assess the significance of changes between pre- and post-intervention testing session. A repeated measures 2-way ANOVA (2 times (pre-post) x 3 training groups x 6 loads) was used to assess the presence of statistically significant changes between



pre- and post-intervention tests in the dynamic force tests. Bonferroni post-hoc comparisons were used in case ANOVA evidenced statistically significant differences. Alpha level for significance was  $P < 0.05$  for all the tests. Partial eta squared ( $\eta^2$ ) and observed power (OP) were also calculated to complete the analysis.

## RESULTS

### *Vibrating platform validation*

The study of vibration patterns evidenced that frequency (Table 3), peak to peak displacement (Table 4) and peak acceleration (Table 5) were not always consistent with their theoretical counterparts (Figure 4).

$f$  was close to the preset frequency and the average error was always lower than 2.0 Hz. Errors did not appear to be load-dependent.

$A$  ranged from 2.6 mm (20 Hz, L2) and 4.4 mm (20 Hz, L0). The median error from the 4 mm peak-to peak displacement declared by the manufacturer was between 5.0% at 20 Hz and 20.0% at 55 Hz, with the 20–40 Hz interval that generally showed a better accuracy but a lower repeatability. Median (IQR)  $\epsilon\%$  in relation with load was 11.3% (5.6%) for L0, 8.8% (8.7%) for L1 and 12.5% (8.8%) for L2.

$a_{peak}$  spanned between 2.1 g (20 Hz, L2) and 19.6 g (55 Hz, L1). The average error from the calculated reference was between 4.7% (30 Hz) and 24.5% (55 Hz). Median (IQR)  $\epsilon\%$  in relation with load was 12.7% (7.5%) for L0, 15.8% (11.3%) for L1 and 17.8% (11.2%) for L2.

\*\*\*\* Table 3,4,5 and Figure 4 near here \*\*\*\*

*Homogeneity of groups*

None of the tests concerning the homogeneity of anthropometric measurements and pre-test parameters evidenced statistically significant differences between groups at the beginning of the experimental protocol (Table 1).

*Test-retest reliability*

All measures gave evidence of a substantial reliability, with ICC values always greater than 0.87. The only variables that had a moderate reliability were the ones related to the time of rise of the isometric force:  $t_{max}$ ,  $t_{30}$ ,  $t_{50}$ ,  $t_{90}$  showed ICCs ranging between 0.55 and 0.70.

*Isometric test*

ANOVA investigations gave no evidence of interaction effect for any of the examined parameter. Main effect for the pre-post factor was significant only for the maximum isometric force ( $P=0.02$ ,  $\eta^2=0.737$ ,  $OP=0.689$ ), while no main effect for treatment was identified in all parameters concerning iMVC. The following trends were reported, though with no statistical significance: median peak force tended to increase in WBV (from 1232.1 (143.8) to 1349.6 (224.7) N) and WBV+ST (from 1304.5 (263.4) to 1378.0 (256.2) N), and to decrease in ST (from 1357.7 (183.0) to 1318.5 (149.9) N);  $t_{30}$ ,  $t_{50}$  and  $t_{90}$  appeared to increase in WBV+ST (respectively, from 73.0 (26.3), 104.0 (28.5), 277.5 (99.5) to 79.0 (17.5), 111.5 (20.3), 298.0 (107.0) ms); to lower in ST (from 100.0 (17.0), 146.0 (31.2), 361.0 (122.0) to 94.0 (9.0), 131.0 (4.0), 314.0 (62.0) ms); and to have an inconstant trend in WBV (from 64.0 (13.3), 92.0 (12.5), 270.0 (18.0) to 71.5 (13.3), 99.5 (24.5), 249.0 (32.8) ms) (Figure 5).

\*\*\*\* Figure 5 near here \*\*\*\*

#### *Dynamic F-v test*

No one of the analysed parameters gave evidence of significant changes between pre and post-intervention tests (Figure 6). As for the iMVC, time was the only factor showing significant effect ( $P < 0.001$ ,  $\eta^2 > 0.373$ ,  $OP > 0.999$  for all the variables).

\*\*\*\* Figure 6 near here \*\*\*\*

#### *Vertical jump tests*

ANOVA tests revealed that all the parameters manifested main effects for the pre-post factor ( $P < 0.002$ ,  $\eta^2 > 0.562$ ,  $OP > 0.989$ ) and a combined effect between time and treatment that was very close to significance for jumping height ( $P = 0.052$ ,  $\eta^2 = 0.389$ ,  $OP = 0.578$ ) and power ( $P = 0.055$ ,  $\eta^2 = 0.384$ ,  $OP = 0.568$ ) in CMJ-15s. Jumping height (best trial) and jumping height and power (mean over 15 s of continuous jumping) sensibly increased only in group ST: they improved from (median (IQR)) 28.0 (1.4) cm, 22.7 (4.2) cm and 18.4 (4.8)  $\text{W} \cdot \text{kg}^{-1}$ , to 30.9 (6.9) cm, 25.7 (1.8) cm and 22.4 (1.2)  $\text{W} \cdot \text{kg}^{-1}$  (Figure 7). Group WBV and WBV+ST showed slight increases of the mean values of these parameters, which were more evident in the combined training group, though never reaching statistical relevance. The median increase of  $H_{max}$ ,  $H_{mean-15s}$  and  $P_{mean-15s}$  were: 7%, 7%, 2% (WBV); 12%, 12%, 10% (WBV+ST).

\*\*\*\* Figure 7 near here \*\*\*\*

## DISCUSSION

The results of the validation study were quite surprising. In fact, we found some inconsistencies in the ability to maintain the vibration load constant when subjects of different mass were using the device in various positions. Measures of the platform behaviour evidenced that the vibrating characteristics were affected by the conditions under which the platform operated (load and pre-set frequency). However, no apparent relationship could be observed. The vibration frequency seemed to be minimally affected by the total mass of the subject ( $\Delta < 2\text{Hz}$ ). More consistent errors concerned the peak-to-peak displacement and the peak acceleration of the platform. Median percentage differences from the theoretical references were up to about 20% for both  $A$  and  $a_{peak}$ , with increased values for higher loads (L2) and higher frequencies ( $>45\text{Hz}$ ). This of course limited the possibilities of our study design and we had to choose an external load that not only could be safely managed by the subject, but also could standardise the vibration magnitude they were exposed to. As previously indicated by other authors (1,2,11) there are currently two types of vibrating platforms designs being marketed: 1) vertical vibrating platforms, whereby the whole platform oscillates up and down; 2) rotating vibrating platforms, whereby the platform oscillates side to side. The former being marketed by most companies. Our results clearly indicated that some appropriate manufacturing quality control should be applied to make sure the vibration dose reported on displays and/or on manufacturer's instruction booklets should be much closer to reality than what we observed. We have observed a lot of difference in platforms from various manufacturers in terms of vibration amplitude and magnitude as compared to the reported values when subjects with different mass stand on them with various posture and/or when the same subjects try to

perform strengthening exercises on such devices. Recent works have suggested the use of specific approaches to make sure vibration is delivered with constant force independently from the force applied to the vibrating source (27,28). Such approach is absolutely necessary for a better understanding of the effectiveness of vibration exposure.

The athletes exposed to WBV training did not report any side effect and the interventions were well accepted within this female cohort. The results of our study showed that our periodised training programme with vibration alone or combined with strength training did not produce significant gains as compared to conventional resistance exercise. However, despite not reaching statistical significance, adding WBV to strength training (WBV+ST) produced a moderate effect in terms of:  $F_{max}$  in dynamic F-v tests (overall +1% respect to WBV and ST);  $H_{max}$  and  $H_{mean-15s}$  in vertical jump tests (+5% and +4% respect to WBV and ST, respectively). Previous studies on female athletes have been mainly focused on acute responses, and encouraging results showed that acutely a short exposure to whole body vibration could improve vertical jumping ability and flexibility (15) and or provide a beneficial effect as a warm-up aid (7). A study conducted using a young athletic female population (team sports and gymnastics) has already shown that WBV performed 3 times per week for 8 weeks could improve knee extensors' strength, flexibility and vertical jumping ability more than performing just normal technical and tactical training (18). Also, when WBV training was compared to a low intensity strength training programme it showed more potential to improve strength in healthy young untrained women (16). Furthermore, recent work from Lamont et al. (23) supports the idea that adding WBV to strength training or adding low frequency WBV between squat lifting sets

produces better gains in strength and rapid force production than strength training alone (24,25). However, despite previous findings, our results are in accordance with other studies conducted on untrained female (37) and female basketball players (20), finding that long term WBV training, performing dynamic loaded or unloaded squats, has no advantages over traditional strength training methods on force production.

While the results of our study do not support the idea that adding WBV to low resistance strength training does produce significant gains in strength, we should consider the limitations of our study, as the resistance chosen was limited by the platform behaviour with added mass as well as its surface area to allow safe execution of squat exercise. In terms of lifting load in fact, the ST group was lifting heavier loads than the WBV+ST group.

The results of our study therefore suggest that WBV cannot substitute parts of strength training loading but could be beneficial only if added to resistance exercise. Recent work seems to suggest that only when vibration is superimposed to high levels of muscle tension ( $>70\%$  of MVC) are able to determine an increase in neuromuscular activation (27,28). Furthermore, resistance exercise performed on a vibration platform seems to elicit greater maximal strength and explosive power gain than resistance exercise performed without vibrations as long as the external load is similar (6-10 RM) (4,29,30,36) supporting this concept that possibly the benefits of vibration can only be visible when vibration is superimposed to high levels of voluntary activation. With this in mind and according to our results on the platform validation, it seems obvious to advice that WBV can only be added to normal strength training in an effective way if the platform used is capable of allowing the user to exercise at the prescribed intensities.



It is then clear that more studies are needed to understand what are the best protocols to benefit from WBV stimulation and technological developments and safety standards are needed to guarantee the quality of devices sold to the general public.

WBV training performed alone and/or in combination with low level resistance exercise has not been shown to produce improvements in force and power generating capacity of the lower limbs in young female athletes after a periodised 8-weeks programme. Further studies are needed to develop better protocols and better guidelines for using long term WBV training alone or in combination with resistance exercise in female athletes, especially using dynamic exercises and external loads with exposure to WBV.

## **PRACTICAL APPLICATIONS**

Vibration may be a potent stimulus for the neuromuscular system. However, the use of vibration as a training modality to enhance the performance of female athletes is still debatable..

The results of our study indicate that adding vibration to the conventional resistance training with light loads does not allow greater strength gains in team sports female athletes as compared to heavier conventional resistance training.

One important element for coaches to consider is that the vibration loading used in this project was not identical for the three groups, and was lower for the WBV+ST group than for ST group.

Furthermore, the study shows the needs to quantify the platform behaviour under loaded conditions in order to determine the appropriate workload for each athlete.

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**FIGURE LEGENDS**

**Figure 1** The strength training exercise carried out by group WBV (a), group ST (b) and group WBV + ST (c).

**Figure 2** Experimental set up for the isometric Maximal Voluntary Contraction (iMVC) tests.

**Figure 3** Experimental set up for the dynamic Maximal Concentric Force (dMCF) tests.

**Figure 4** Percentage error of vibrating frequency ( $f$ ), peak-to-peak displacement ( $A$ ) and maximal acceleration ( $a$ ), under different conditions of preset frequencies. Measures are presented as the median and IQR over the whole set of repetition and load conditions.

**Figure 5** Maximum force (a) and time to 50% of maximum force (b) during iMVC tests. Data are reported as group median and interquartile ranges. No statistically significant differences were detected by repeated measures ANOVA.

**Figure 6** Maximum force (a), velocity (b) and power (c) during dMVC tests. Within each figure, graphs are divided by training groups (WBV, WBV+ST, ST) and load (%BM). Results are reported as group median and interquartile range. No statistically significant differences were detected by repeated measures ANOVA.

**Figure 7**  $H_{max}$  (a) and  $P_{mean-15s}$  (b) during CMJ tests. Data are reported as group median and interquartile ranges. (\*) indicates statistically significant differences detected by repeated measures ANOVA ( $p < 0.05$ ).

FIGURES

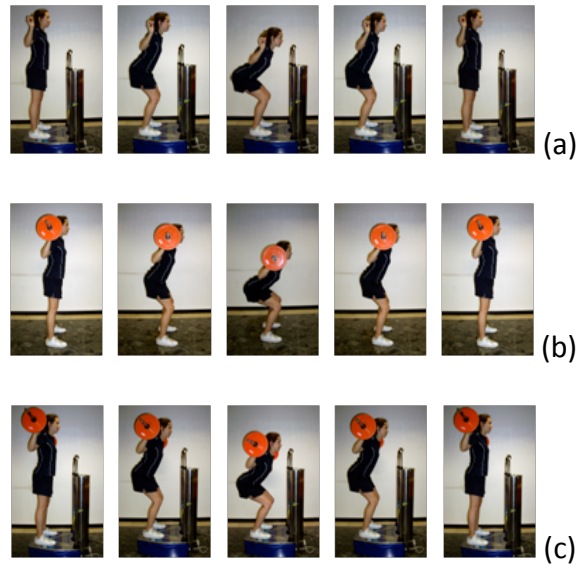


Figure 1



Figure 2

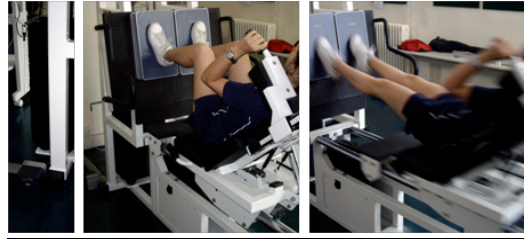


Figure 3

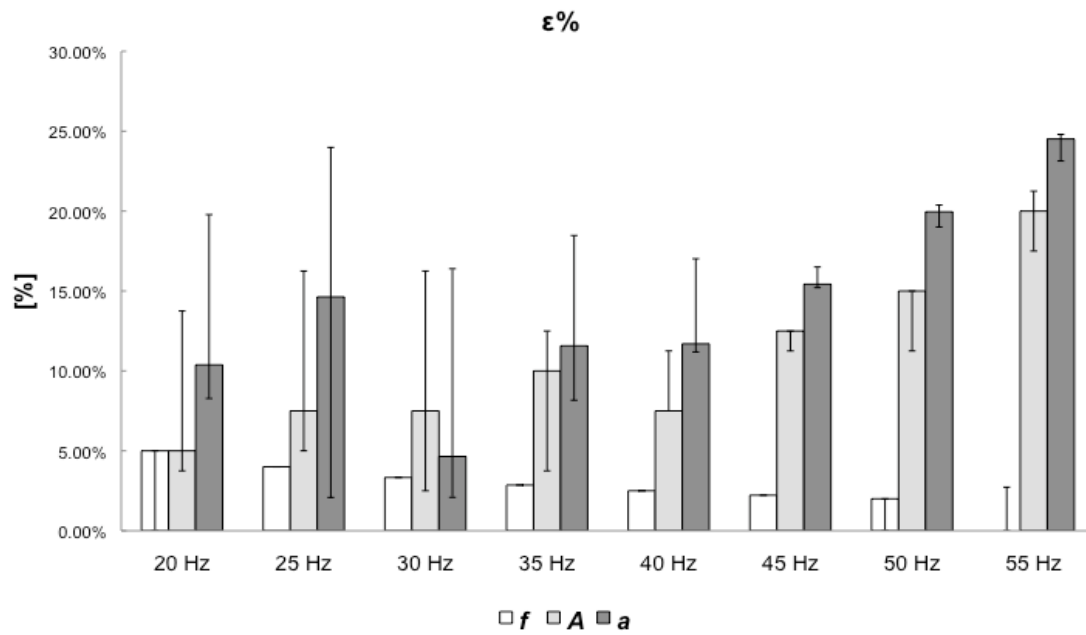


Figure 4

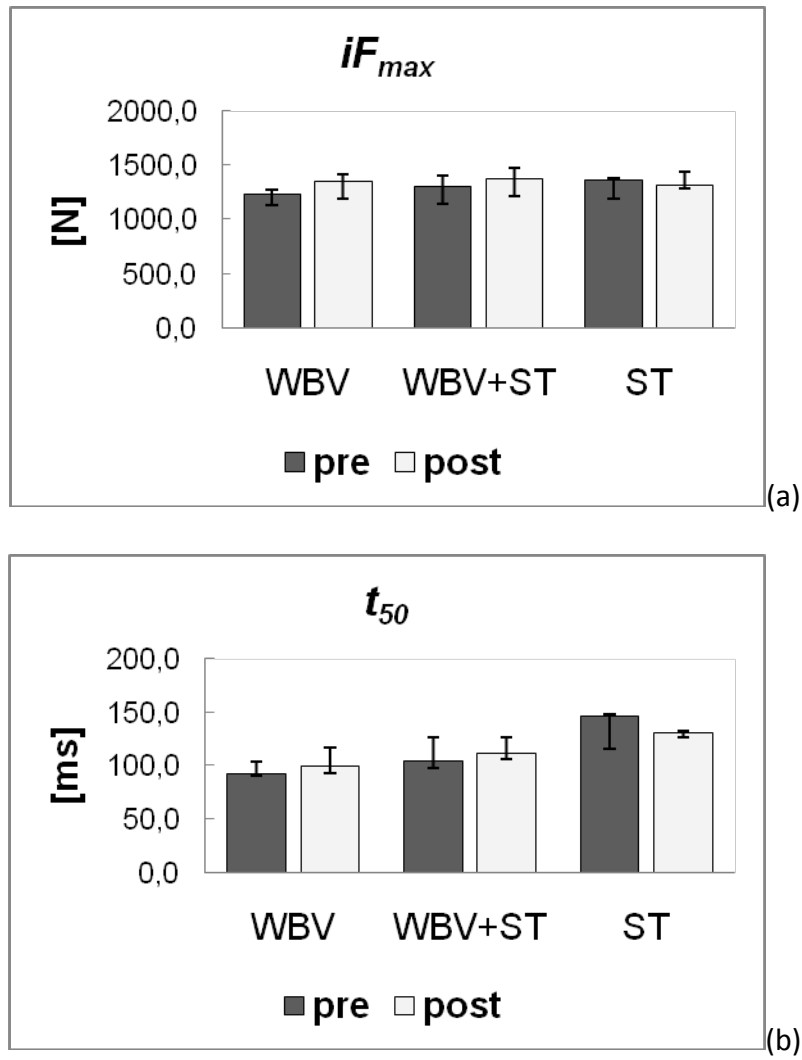


Figure 5

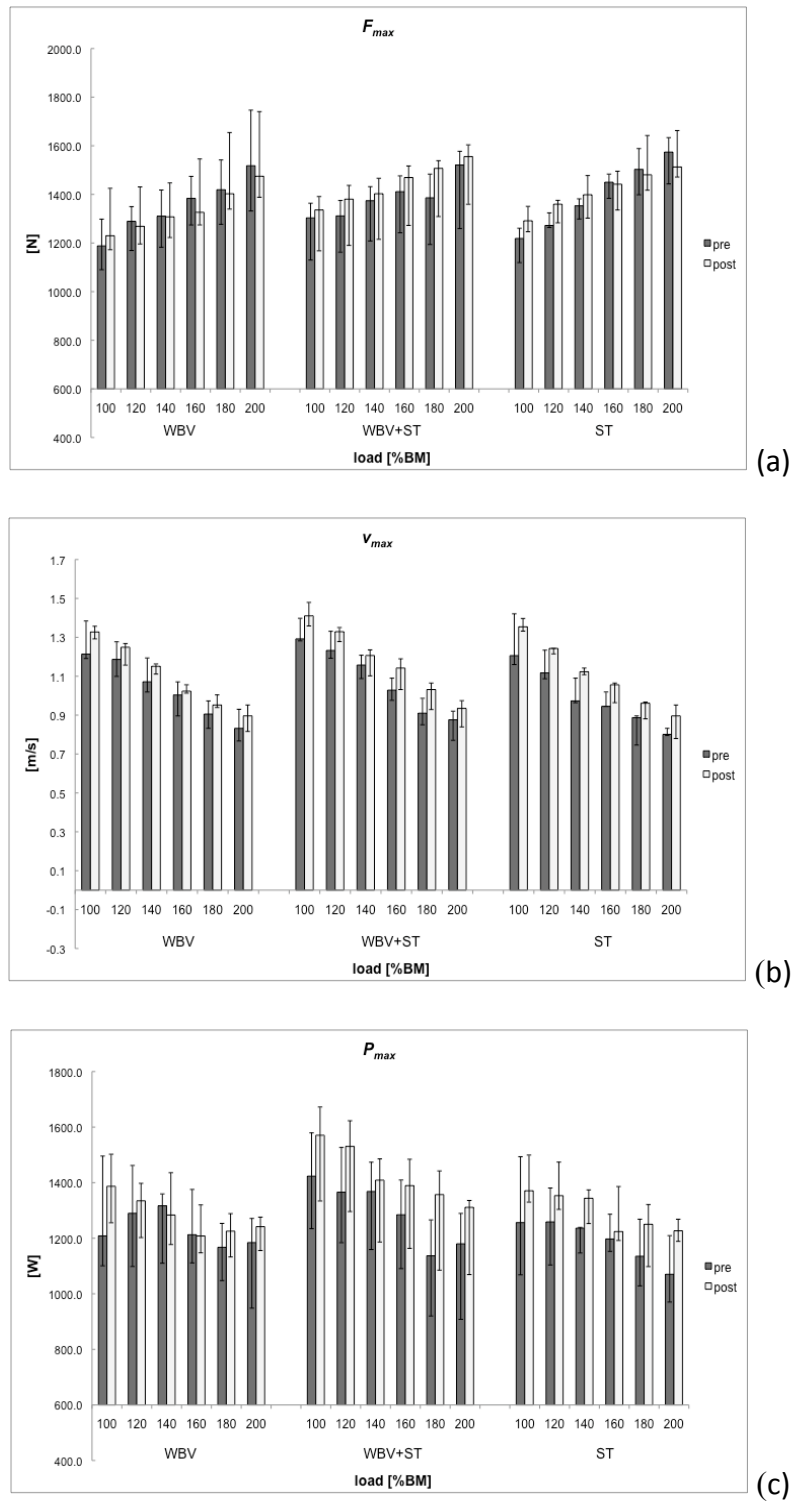


Figure 6

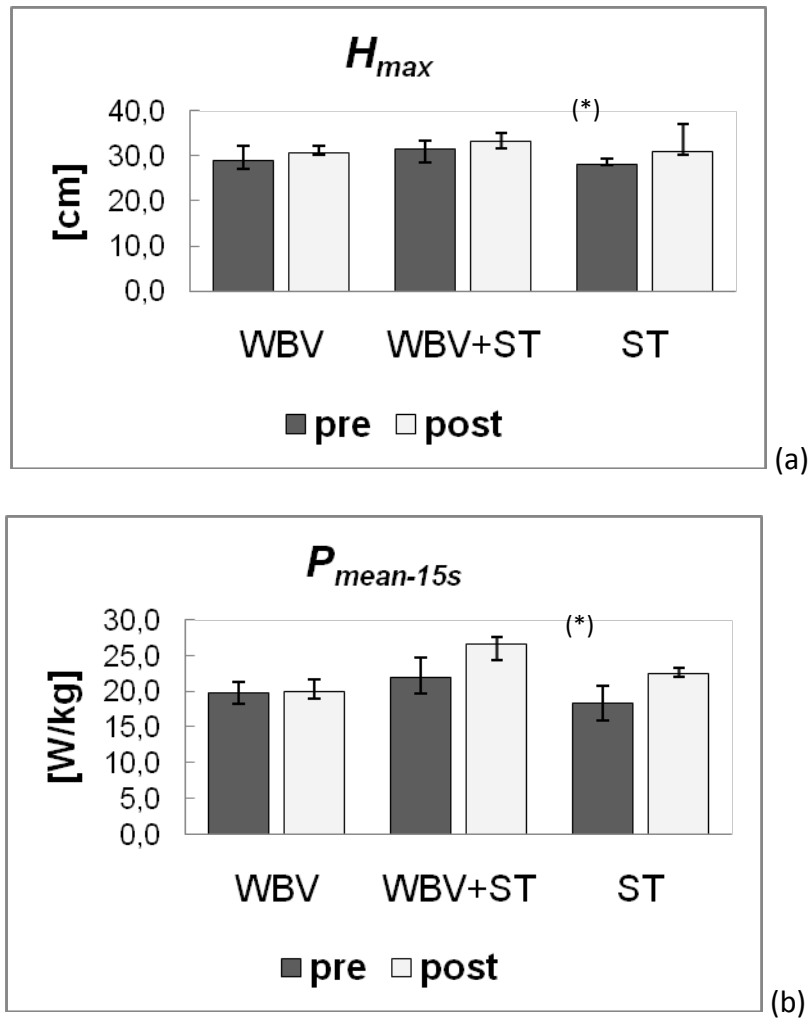


Figure 7



## TABLES

**Table 1** Description of the population of each group

	WBV	ST	WBV+ST	<i>p</i> -value
Composition	4 soccer players	4 soccer players	4 soccer players	-
	2 softball players	2 softball players	2 softball players	
Age (yrs)	24.0 ± 5.4	22.2 ± 2.1	26.3 ± 5.1	0.215
Height (cm)	166.3 ± 4.9	166.0 ± 6.2	166.5 ± 6.6	0.898
Body mass (kg)	58.4 ± 9.1	61.4 ± 8.2	56.2 ± 5.8	0.725
Fat mass (%)	22.2 ± 11.1	18.6 ± 3.2	14.6 ± 1.3	0.166

Values are mean ± *SD*. *p*-value: results of Kruskal-Wallis Test between pre-test group means.

WBV = Whole Body Vibration group; ST = conventional strength training (with barbell) group;

WBV+ST = combined strength training (vibration and barbell) group.

**Table 2** Description of the experimental training design

activity	week	group		
		WBV	ST	WBV+ST
test	w0	PRE-TESTS		
training	w1	6 sets x 6 reps:	6 sets x 6 reps:	6 sets x 6 reps:
		25 Hz	60% BM	25 Hz + 30% BM
training	w2	6 sets x 6 reps:	6 sets x 6 reps:	6 sets x 6 reps:
		25 Hz	50% BM	25 Hz + 30% BM
training	w3	6 sets x 6 reps:	6 sets x 6 reps:	6 sets x 6 reps:
		30 Hz	66% BM	30 Hz + 33% BM
taper	w4	4 sets x 6 reps:	4 sets x 6 reps:	4 sets x 6 reps:
		25 Hz	60% BW	25 Hz + 30% BM
training	w5	6 sets x 6 reps:	6 sets x 6 reps:	6 sets x 6 reps:
		30 Hz	66% BM	30 Hz + 33% BM
training	w6	6 sets x 6 reps:	6 sets x 6 reps:	6 sets x 6 reps:
		35 Hz	72% BM	35 Hz + 36% BM
training	w7	6 sets x 6 reps:	6 sets x 6 reps:	6 sets x 6 reps:
		35 Hz	72% BM	35 Hz + 36% BM
taper	w8	4 sets x 6 reps:	4 sets x 6 reps:	4 sets x 6 reps:
		30 Hz	66% BM	30 Hz + 33% BM
test	w9	POST-TESTS		

WBV = Whole Body Vibration group; ST = conventional strength training (with barbell) group;

WBV+ST = combined strength training (vibration and barbell) group; BM = body mass.

**Table 3** Actual vibrating frequency (Hz) of the force platform.

$f$ REF	L0	L1			L2		
	-	KF90	KF45	EK	KF90	KF45	EK
20	20	21	21	20	21	21	20
25	26	26	26	26	26	26	26
30	31	31	31	31	31	30	31
35	36	36	36	36	36	36	36
40	41	41	41	41	40	41	41
45	46	46	46	46	45	46	46
50	51	49	50	51	49	50	50
55	55	53	55	55	53	54	55
$\epsilon\%$	2.4% (1.5%)	2.7% (1.2%)			2.5% (3.4%)		

Measures (Hz) are the median values over 3 acquisitions of 5s each. REF is the frequency reported by the device (preset frequency). L0= no load; L1= 55 kg load; L2= 90 kg load. KF90= knee flexed at 90 deg; KF45= knee flexed at 45 deg; EK= extended knee and heel raised.  $\epsilon\%$  is the median (IQR) percentage error (in each load condition) with reference to the theoretical frequency.

**Table 4** Actual peak-to-peak displacement (mm) of the force platform.

<i>f</i>	<i>A</i> REF	L0	L1			L2		
		-	KF90	KF45	EK	KF90	KF45	EK
20	4.0	4.4	3.9	3.8	4.1	3.3	2.6	4.2
25	4.0	3.9	3.4	4.3	4.3	2.7	3.3	4.1
30	4.0	3.4	3.3	4.3	4.1	2.7	4.1	3.9
35	4.0	3.6	3.4	3.8	3.9	3.3	4.1	3.6
40	4.0	3.7	3.1	3.7	3.7	3.6	3.9	3.5
45	4.0	3.5	3.3	3.6	3.5	3.5	3.6	3.5
50	4.0	3.4	3.6	3.4	3.3	3.6	3.4	3.5
55	4.0	3.1	3.7	3.2	3.2	3.1	3.3	3.3
$\epsilon\%$		11.3% (5.6%)	8.8% (8.7%)			12.5% (8.8%)		

Measures are the median values over 3 acquisitions of 5 s each. *f* is the preset frequency (Hz).

REF is the theoretical displacement. L0= no load; L1= 55 kg load; L2= 90 kg load. KF90= knee flexed at 90 deg; KF45= knee flexed at 45 deg; EK= extended knee and heel raised.  $\epsilon\%$  is the median (IQR) percentage error (in each load condition) with reference to the theoretical displacement.

**Table 5** Actual peak-acceleration of the force platform.

$f$	$a$ REF	L0	L1			L2		
		-	KF90	KF45	EK	KF90	KF45	EK
20	3.2	3.3	3.0	2.9	3.6	2.5	2.1	2.7
25	5.0	5.0	4.0	5.1	5.2	3.4	3.6	4.3
30	7.2	6.2	5.9	7.1	7.1	5.2	6.9	7.1
35	9.8	8.7	7.4	8.6	9.4	6.6	9.6	8.7
40	12.9	11.4	9.1	11.5	11.4	10.5	11.9	10.9
45	16.3	13.8	12.1	13.8	13.6	14.6	13.8	13.6
50	20.1	16.1	16.5	16.1	15.9	16.7	16.0	16.1
55	24.3	19.0	19.6	18.3	18.4	18.0	18.4	18.3
$\epsilon\%$		12.7% (7.5%)	15.8% (11.3%)			17.8% (11.2%)		

Measures (expressed as a multiple of g acceleration) are the median values over 3 acquisitions of 5 s each.  $f$  is the preset frequency (Hz). REF is the theoretical acceleration ( $a = A \cdot (2\pi f)^2$ ). L0= no load; L1= 55 kg load; L2= 90 kg load. KF90= knee flexed at 90 deg; KF45= knee flexed at 45 deg; EK= extended knee and heel raised.  $\epsilon\%$  is the median (IQR) percentage error (in each load condition) with reference to the theoretical maximal acceleration.